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Gravity variations before the Menyuan Ms6.4 earthquake

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ABSTRACT

In order to study the relationship between gravity variation and Menyuan Ms6.4 earthquake, gravity variation characteristics in mid-eastern of Qilian Mountain were analyzed based on the 2012–2015 relative gravity datasets. The results indicated that the gravity changes in mid-eastern of Qilian Mountain increased gradually, while gravity changes around Menyuan remarkably. Besides, great positive-negative gravity changing gradients appeared along the Lenglongling Fault which was located at the north of Menyuan, and the 2016 Menyuan Ms6.4 earthquake occurred near the junction of positive and negative gravity changes.

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1. Introduction

As we all know, earthquakes usually occurs along with mass transfer and gravity variations. This phenomenon has been demonstrated by many researches, e.g. 1964 Niigata earthquake in Japan [1], 1964 Alaska earthquake in USA [2], and the 1968 Inangahua earthquake in New Zealand [3]. Since the 1980s, many domestic scholars have been studying on the relationship between active faults and earthquakes based on the gravity data, and many gratifying results have been obtained: Wang et al. [4] studied the gravity changes of active faults around Beijing, and the results showed approximately 100×10^{-8} ms^{-2} gravity changes, induced by the Tangshan earthquake, along the NNE and NS faults. The temporal and spatial distribution patterns of gravity field provided basis for predicting the time and location of strong earthquake by repeated gravity measurements. Sun et al. [5] studied the gravity changing characteristics in Xianshuihe Fault, finding that there were obvious gravity anomaly

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before the Batang, Xiaojin, Lijiang earthquakes. Zhu et al. [6–10] analyzed the correlation between the gravity changing characteristics of Longmen Mountain Fault and the Wenchuan Ms8.0 earthquake, using the temporal and spatial patterns of regional relative gravity changes in many periods, to obtain a conclusion that there is a close relation between the gravity changes and the tectonic movements of Longmen Mountain Fault. Besides, the effects of gravity changes on the earth surface, caused by the mass transfer and tectonic deformation of active faults, were well reflected by the gravity surveying data.

Mid-eastern of Qilian Mountain (MEQM), located at the northeastern of Tibet Plateau block, is one of the regions with the most intense movement and high frequency of earthquakes in China. Since the 1900s, many great earthquakes have occurred around the mid-eastern of Qilian Mountain, e.g. Haiyuan Ms8.5 earthquake in 1920, Gulang Ms8.0 earthquake in 1927, the Shandan Ms7.25 and the Minqin Ms7.0 earthquake in 1954. Since 1990, there have been more than 10 great earthquakes (Ms > 5.0) occurred in this region, and many earthquakes with magnitudes reach Ms5.0 occurred in recently years.

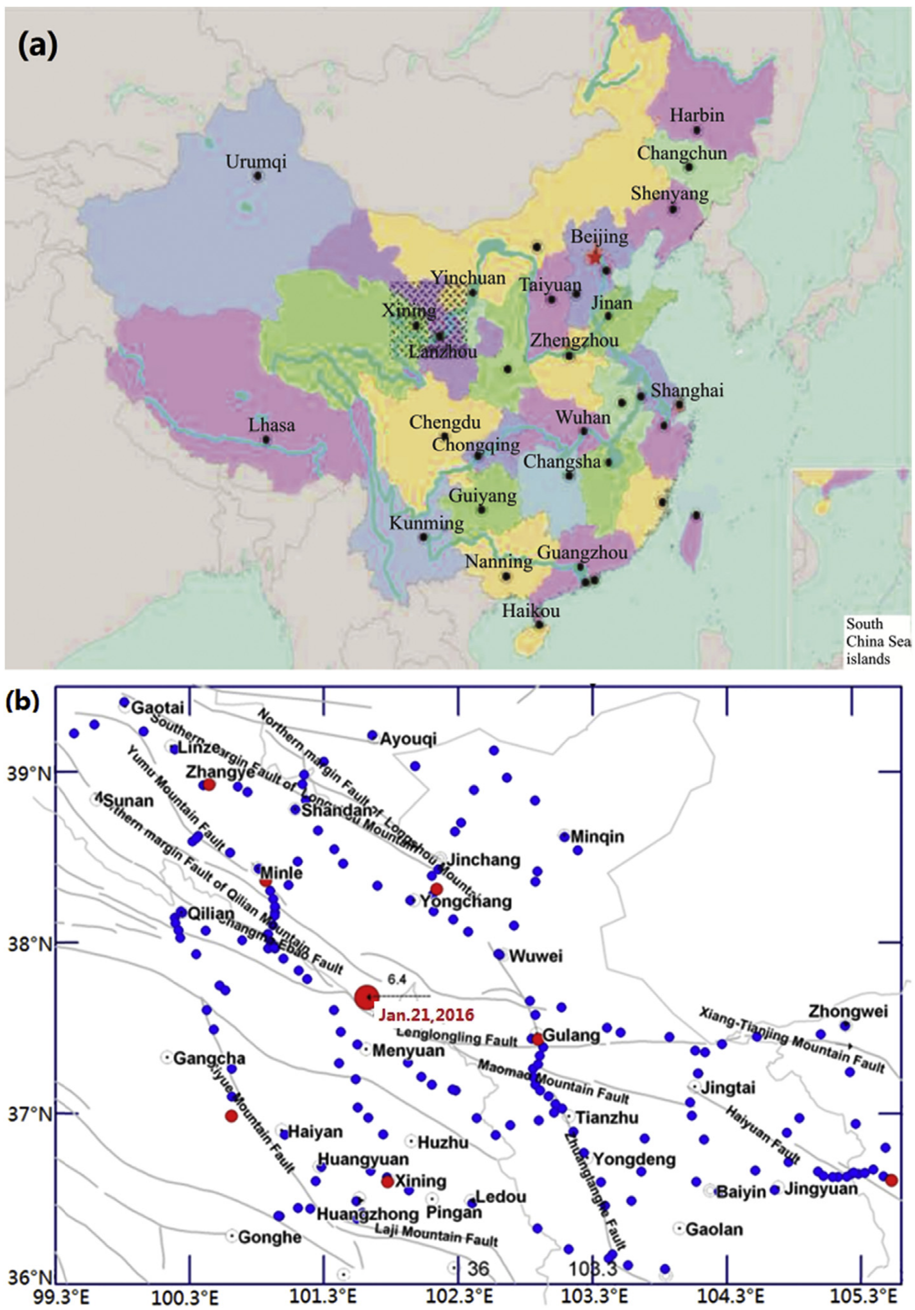

Fig. 1 – a: Hexi area in China; b: Distribution of relative gravity surveying points and tectonic structure in/near the mid-eastern of Qilian Mountain. (The blue dots represent the surveying points, the small red dots the stationary points, the grey lines the faults).

The 2016 Menyuan Ms6.4 earthquake occurred on January 21, 2016, and the epicenter was located at 101.62°E, 37.68°N with source depth being 10 km. During Sep. 2014 to Sep. 2015, and Apr. 2015 to Sep. 2015, gravity variation showed positive-negative transfer along the both sides of north margin of Qilian Mountain Fault (QMF) and the Lenglongling Fault (LLF). Qilian-Menyuan-Gulang-Minqin, located generally along the QMF and LLF, showed intense gravity gradient patterns. This distribution pattern of gravity field represented active tectonic movements in this region.

In this study, we processed the relative gravity datasets span from 2012 to 2015 with a unified standard; analyzed the gravity changes characteristics with different time scale and studied the relationship between the earthquake and the gravity changes before and after the earthquake.

2. Overview of data

Since the beginning of 1990s, we have been measuring the relative gravity network of Hexi area (referred to as "Hexi", Fig. 1a) two times every year, covering Hexi corridor in Gansu Province and Qilian Mountain in Qinghai Province and its surrounding areas where many NWW and NWW active faults are located: southern margin fault of Longshou Mountain, northern margin fault of Qilian Mountain, Changma-Ebao Fault, LLF, eastern margin fault of Yumu Mountain, Zhuanglanghe Fault and Haiyun Fault, etc. Hexi relative gravity measurements network contains 178 measuring points, 188 measuring sections, and single measurement line reaches 3700 km. Besides, this measurements network also includes another 30 measurement points and measuring line of 160 km belonging to 3 cross fault comprehensive observation fields. All the measurement points are plotted as blue dots in Fig. 1b.

In this study, the 2012–2015 gravity datasets of Hexi relative gravity measurement network were processed with a unified standard. The adjust software is Lacoste Gravimetry Adjustment (LGADJ) proposed by Chinese Earthquake Administration (CEA), 7 stationary points, shown in Fig. 1b as small red dots, were selected as quasi-stable points for quasi-stable adjustment. In order to obtain reasonable adjust precision, prior variance of each measurement instrument were reasonably determinated by integrated analysis of multi period adjustment data and many times adjustments after analysis of the variance of each instrument. Besides, more accurate gravity changes were obtained by removing the effects of environment change and human factors. When plotting the spatial distributions of gravity changes, we processed the adjusted gravity data by Kriging algorithm, as well as 300 km Gaussian filter. Furthermore, in order to eliminate the influence of gross errors and superficial factors, spline smoothing was performed using the insertion node method, which could highlight the gravity effect of tectonic factors.

3. Analysis of gravity changes

3.1. *Accumulative characteristics of gravity changes in mid-eastern of Qilian Mountain*

The accumulative gravity changes of mid-eastern of Qilian Mountain are shown in Fig. 2. The Fig. 2a shows gravity accumulation in mid-eastern of Qilian Mountain from May 2012 to Sep. 2014. The local anomaly appears around Menyuan, and the positive-negative gravity accumulation differences reach approximately 100 × 10^{-8} ms^{-2}, and Ms4.9 earthquake in 2012, Ms5.1 earthquake in 2013 and Ms4.3 earthquake in 2014 have occurred in this region.

The Fig. 2b shows the spatial distribution of gravity accumulation around mid-eastern of Qilian Mountain from Sep. 2013 to Sep. 2015. Positive gravity changes appear in the northwest, and the negative ones appear in the southeast. The region covered Minle-Shandan-Yongchang-Minqin and the region covered Huangyuan-Reshui show positive gravity changes. However, the area between the two regions shows negative gravity changes, constructing four-quadrant distribution of gravity changes with other regions. The intense positive-negative gravity changing gradients formed along QMF and LLF, and the maximum

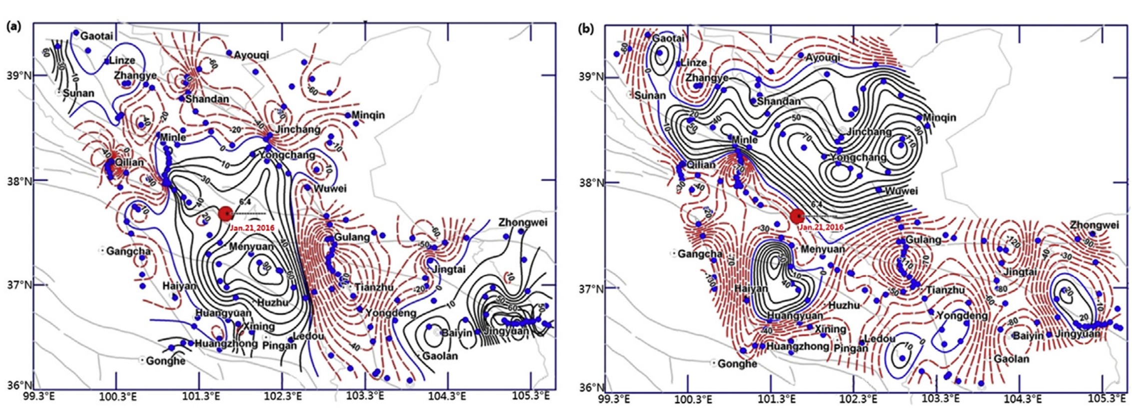

Fig. 2 – Accumulation of gravity changes in mid-eastern of Qilian Mountain. (The blue dots denote the surveying points, the red dots the epicenter; the red dashed lines, black solid lines, the blue solid line represent negative gravity changes, positive gravity changes and zero ling of gravity changes, respectively).

value is beyond 160 $\times$ 10^{-8}ms^{-2}. The Menyuan *Ms*6.4 earthquake occurred near the junction of positive and negative gravity changes.

3.2. *Characteristics of annual gravity change of mid-eastern Qilian Mountain*

The annual gravity changes of mid-eastern Qilian Mountain are shown in Fig. 3. The Fig. 3a shows the gravity changes from May 2012 to May 2013. From Fig. 3a, we can see there were no obvious gravity changes in this region, and the positive signals appeared in the western region, with the eastern region showing negative signals respectively. While local negative signals appeared around Tianzhu. The gravity changes from May 2013 to Apr. 2014 are shown in the Fig. 3b. During this period, the gravity changes in the Qilian Mountain were negative and positive signals appeared in the south of Qilian Mountain, while negative signals appeared around Wuwei and Minqin which located at the north of Qilian Mountain.

The gravity changes from May 2014 to Apr. 2015 are shown in Fig. 3c. During this period, the gravity changes were contrast to those from May 2013 to Apr. 2014, i.e. the negative signals from May 2013 to Apr. 2014 changing to positive ones. The gravity changes formed four-quadrant distribution between Gulang, Menyuan, Xining and Tianzhu, and there was still local anomaly from Tianzhu to Haiyuan which showed positive signals. The Fig. 3d shows the gravity changes from Sep. 2014 to Sep. 2015, in which gravity changing signals were positive in the northwest and negative in the southeast, and the junction of positive and negative gravity changes between Hua Temple and Qilian was along QMF and LLF. Intense gravity changing gradients appeared in both sides of QMF and LLF, with the maximum difference being approximately 140 $\times$ 10^{-8} ms^{-2}, and the Menyuan *Ms*6.4 earthquake occurred near the junction of positive and negative gravity.

3.3. *Characteristics of semi-annual gravity change of mid-eastern Qilian Mountain*

The semi-annual gravity changes of mid-eastern Qilian Mountain from Sep. 2012 to Sep. 2015 are shown in Fig. 4. The gravity changing processes generally is from weak to strong. The gravity changes around Menyuan experienced dramatic changes: positive-negative-positive-negative, and then the gravity changes surrounding Menyuan formed gravity gradients along the faults. At last, the Menyuan *Ms*6.4 earthquake occurred near the junction of positive and negative gravity. In the duration, gravity changed weakly from N-negative/S-positive in Sep. 2012 to May 2013 (Fig. 4a) to W-positive/E-negative in May 2013 to Sep. 2013 (Fig. 4b), and the gravity zero line was located from Yongchang to Huzhu. The gravity changed intensely in mid-eastern of Qilian Mountain from Sep. 2013 to Apr. 2014 (Fig. 4c). The gravity changing spatial patterns formed four-quadrant distribution and the center was located at the center of Gulang, Menyuan, Huzhu and Wuwei. The gravity changes in Sep. 2014 to Sep. 2014

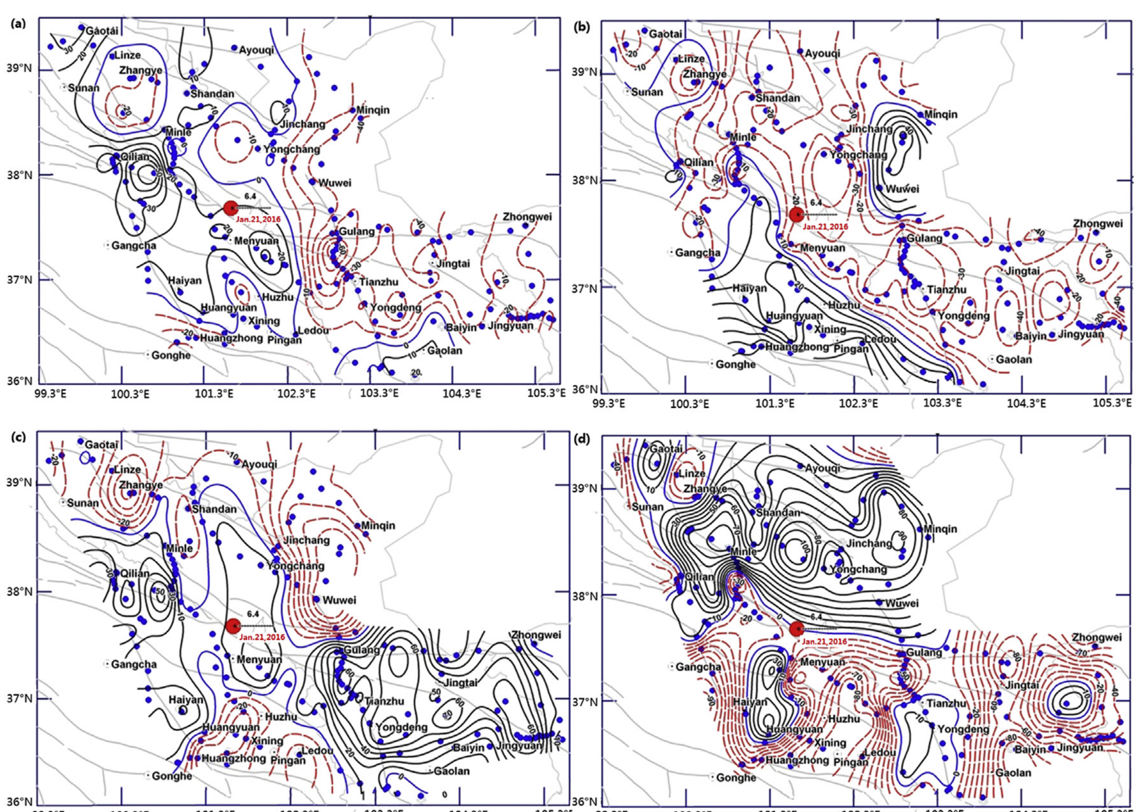

Fig. 3 — Characteristics of annual gravity changing of mid-eastern Qilian Mountain.

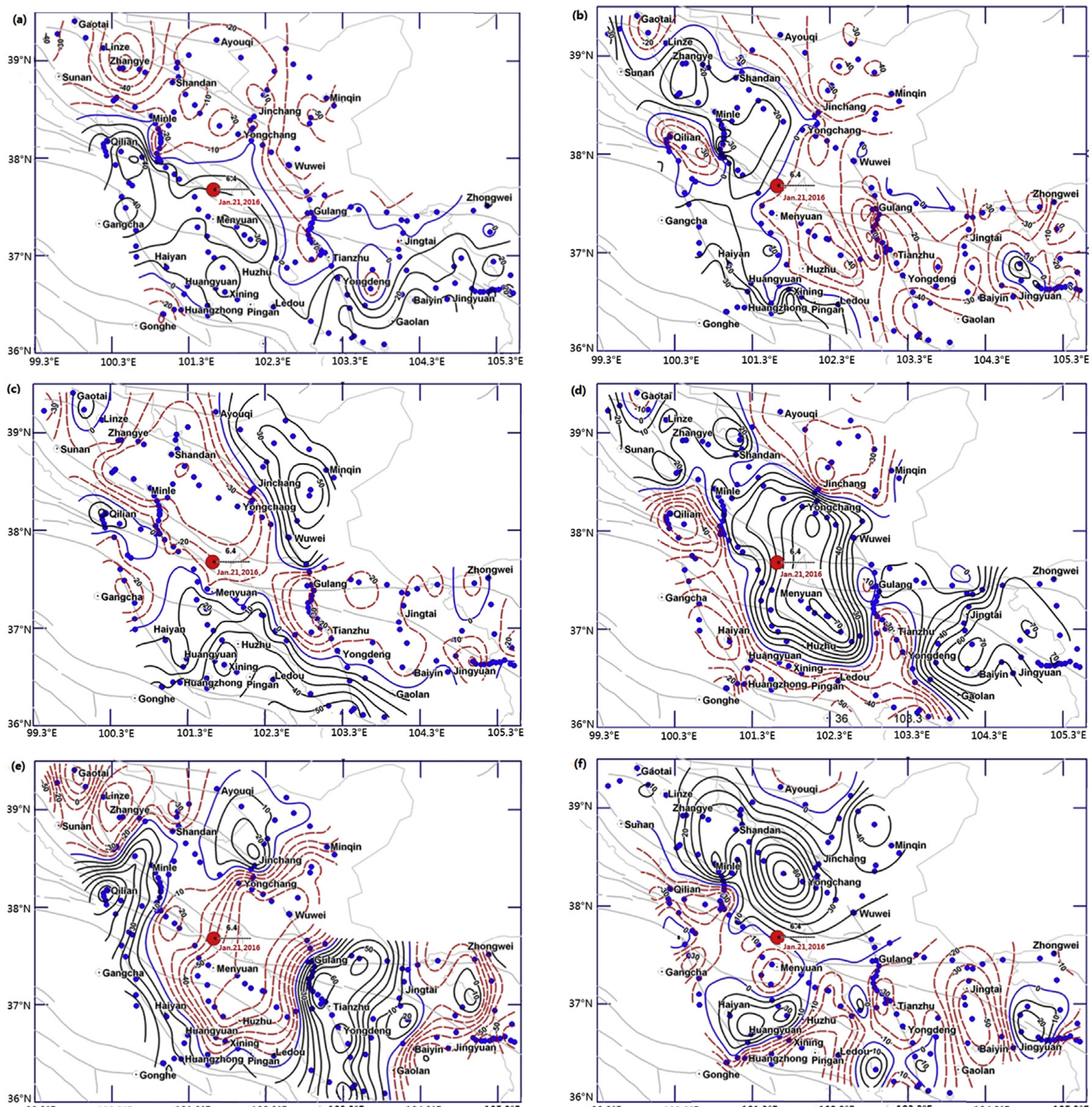

Fig. 4 — Semi-annual gravity changing characteristics of mid-eastern of Qilian Mountain.

(Fig. 4d) showed adverse variation respect to those in Sep. 2013 to Apr. 2014, and the local gravity signals around Menyuan were positive. There were great gravity changes in the whole Hexi area from Sep. 2014 to May 2015 (Fig. 4e), the local gravity changes around Menyuan being negative, contrast with the previous period results. Besides, local positive signals appeared around Ebao in Qinghai Province, Gulang and Tianzhu in Gansu Province, forming the gradients of positive and negative gravity differences. In the latest period of measurement from May 2015 to Sep. 2015, new gravity changing distribution patterns appeared in mid-eastern of Qilian Mountain: positive in northwest and negative in the southeast. Positive and negative gravity changes gradient appeared in both sides of Changma-Ebao Fault and LLF, and the Menyuan Ms6.4 earthquake occurred near the gravity zero line. Furthermore, the local gravity signals appeared near Jingtai, and the local positive gravity signals in Tianzhu disappeared in this duration.

4. Relationship of gravity changes and earthquakes

The active faults usually caused tectonic deformations due to the intense relative motions of two sub-faults, which could lead to stress accumulation and finally earthquakes. So the earthquakes usually occurred in/near the boundaries of active blocks and active faults zone. For example, the Lushan Ms7.0 earthquake on April 20, 2013 occurred in the south of Longmen Mountain Fault with the strike being NE. Before the Lushan earthquake, obvious large scale regional gravity anomaly and associated intense gravity gradients appeared in the epicenter area and its vicinity, and the Lushan earthquake occurred at the turning parts of gravity gradients [10].

According to the former researches, there would be regional gravity anomaly and intense gravity gradients along the active faults before earthquakes, as well as the local gravity anomaly in/near the epicenter. For example, before the 1995 Yongdeng Ms5.8 earthquake and the 2000 Jingtai Ms5.9 earthquake, regional gravity anomaly appeared and the intense gravity gradients were along the direction of main active faults: negative gravity changes in the southwest (mountain area), and positive gravity changes in the northeast (basin area). Besides, the gravity contours bended eastward, and formed some non-uniform local anomaly regions in the mid-east of surveying region [11–13]. Before the 2003 Minle Ms6.1 earthquake and Ms5.8 earthquake, regional gravity anomaly also appeared and the intense gravity gradients were along the direction of main active faults, and the local gravity anomaly appeared in/near the epicenter. The gravity gaps near Minle, Shandan, Ebao, Yongchang and Tianzhu were relative decline, and the earthquake occurred at the edge of gravity changing gradients [14].

Before the 2016 Menyuan Ms6.4 earthquake, the gravity field in mid-eastern of Qilian Mountain changed from weak to intense, and formed the gravity changing gradients along the LLF near Menyuan. Then the Menyuan Ms6.4 earthquake occurred near the gravity zero line. In 2012 and 2013, there were Ms4.9 and Ms5.1 earthquakes occurred in Ebao-Menyuan, and we analyzed the gravity changes in this region, and proposed that the two earthquakes indicated the increase of material movement and continuous of underground stress in mid-eastern of Qilian Mountain. Considering no great earthquake (Ms > 6.0) have occurred in this region before, we concluded that these two earthquakes maybe the precursor of energy release in this region, and it worth paying attention to [15].

5. Conclusions and discussion

The mid-eastern of Qilian Mountain is located in the northeastern margin of Tibet Plateau, and due to the push from Tibet Plateau, as well as the block from Alashan plate and Ordos plate, the stresses in the mid-eastern of Qilian Mountain accumulate continuously until the sudden release, exciting the Menyuan Ms6.4 earthquake. Non-tidal gravity changes mainly reflect the migration of underground material and the changes of material density, and the local gravity anomaly usually caused by the activities of tectonic faults, so there are some certain correlations between the gravity changes and the fault strike [16]. According to the gravity changing patterns from Sep. 2013 to Sep. 2015 (Fig. 2a), the annual gravity changing patterns (Fig. 3) and the semi-annual gravity changing patterns (Fig. 4), during the gestation of Menyuan Ms6.4 earthquake, the stresses surrounding the Changma-Ebao Fault, Tuolaishan Fault and the Lenglongling Fault accumulated continuously and then causing a series of complex gravity changes. In a short time before the Menyuan earthquake, the gravity changing gradients formed along Lenglongling Fault, and the Menyuan Ms6.4 earthquake occurred near the Lenglongling Fault with the epicenter located near the zero line of gravity changes.

Most great earthquakes occurred accompanied by gravity changing gradients along the active faults. However, each location of earthquake on the gradients was different due to the characteristics of the active faults, and this should be studied further in the future.

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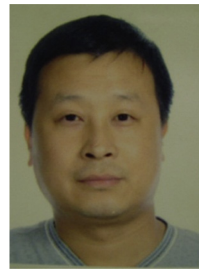

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